Forced Induction Rotary Valve System

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Abstract

The current valve design found in modern four-stroke *internal combustion engines* employs *poppet style valves* for fresh air/fuel mixture admission to the *combustion chamber*, as well as the relief of burnt gases away from the *cylinder*. These *valves* are relatively simple in design and their lifetime is approximately equal to the life span of the entire engine. Current *valves*, however, cause intake and exhaust obstruction, thus reducing the overall efficiency. In addition, the excessive number of parts involved in a typical *valve-train* cause friction, which lead to reduction in net power output. Our objective is to redesign the engine intake/exhaust system in a way that we can eliminate most of the auxiliary parts of the *valve-train*. In doing so, we plan to replace the *poppet style valves* with a screw form that will rotate. This rotation will create forced flow to and from the *combustion chamber*, thus increasing efficiency. For the purposes of this design, we intend to modify the *valve seats* of an existing engine head to a design of a *rotary type valve*. Through our design project, we will model a new design and create a prototype. We will also compare our theoretical efficiencies to those of the existing poppet valve design.

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Problem Background

The internal combustion four-cycle engine is a machine that has withstood the test of time. It was designed as a pure mechanical device and has changed very little over the years. The *internal combustion engine* has been widely used and has many applications. Proof of this can be in its presence in everything from lawn mowers to airplanes for the last one hundred years. Unfortunately, there is an efficiency and reliability tradeoff when designing any piece of machinery. Such is the case with most four-cycle *internal combustion engines*. To deny its proven past would be a great mistake. However, there is always room for improvement.

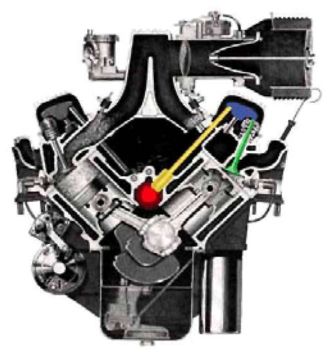


Figure 1: Valve-train of an overhead valve engine

When analyzing an engine's efficiency and output, the most important area of focus is the engine's *cylinder heads*. They are responsible for inducing the air/fuel mixture into the *combustion chamber* for combustion, as well as removing burnt gases from the *combustion chamber* after the process of combustion is completed. Air/fuel mixture and exhaust gases flow through *intake* and *exhaust valves*, respectively. These *valves* are controlled by a *camshaft* and, in some cases, *pushrods* and *rocker arm* linkages. The *valve-train* of an overhead valve engine can be seen in Figure 1 and an overhead cam *valve-train* can be seen in Figure 2. In theory, the more air and fuel an engine pumps into the *combustion chamber*, the more power it will produce. In addition to this, an engine's efficiency can be increased if *combustion chamber* sealing is maximized and frictional losses are minimized.

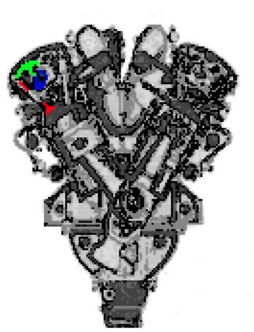


Figure 2: Valve-train of an overhead cam engine

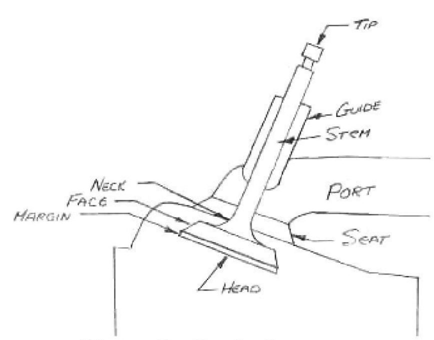


Figure 3: Typical poppet style valve, spring removed

In a *poppet valve* equipped *cylinder head*, the largest flow obstruction is the *valve* itself, as shown in Figure 3. This *valve* is a major restriction in most four-cycle engines due simply to the nature of its design. The valve head is slightly larger than the port opening and is used to seal the port when the *valve* is closed. When the *valve* is open, air and fuel or exhaust gases must flow around the head of the *valve*. Although this type of *poppet style valve* is very rugged and allows for a reliable seal, it is not ideal for fluid flow. In addition to flow obstruction, the cam driven *valve-train* also requires a considerable amount of energy to operate. Each *poppet valve* is held against its *valve seat* by a spring, which is compressed when the *valve* is opened. This spring keeps tension in the *valve-train* and maintains *valve timing*. Considering that there is a spring used on each *valve*, it can be conceived that there is a measurable amount of energy loss in the spring compression alone. A more efficient design would allow the *valve* to function properly without the losses associated with spring tension.

Status Review / Market Studies

Auto manufacturers have attempted to design an efficient *rotary style valve* for the *internal combustion engine*, dating back to Kawasaki in the mid 60's, and possibly earlier. Designs continue to present day and a very good example of a *rotary valve* has been designed by Coates International, Ltd. Engines [1]. These efforts have proven that efficiency, horsepower, emissions, and oil life all benefit greatly by implementing a *rotary style valve* into the *internal combustion engine*. Fuel efficiency increases, as does engine horsepower and torque.

The problem area common to most rotary valve designs is valve sealing. Engine *intake* and *exhaust valves* are subject to very high pressures during the compression and power strokes of a four-cycle engine. It is very difficult to improve upon the sealing ability of a simple *poppet style valve*. *Poppet style valves* not only seal very well, but they seal dependably for the lifetime of most engines. A major design goal of a *rotary valve* should be to create a seal that is comparable to that of the sealing offered by a typical *poppet valve*.

Methods for Solution

In an attempt to overcome the losses and inefficiencies of the *poppet style valve* and its related components, as well as to address the sealing issues common with even the most recent rotary valve technology, we have compiled the following pre-concept designs.

First, our design will enable free flow of both intake and exhaust gases without the restriction common with the *poppet valve*. This is a universal goal of all *rotary style valves*. Our design, however, is set apart by the fact that we intend to use the rotating motion of our *valve*, as opposed to the linear motion of the *poppet valve*, to improve flow through the *combustion chamber*. We intend to use this rotating motion to charge the *combustion chamber* with fresh air and fuel, and similarly draw spent gases from the chamber. In essence, our *valve* doubles as a screw compressor for the inlet and as a screw extractor for the exhaust. We intend to investigate the possible advantages of this type of configuration by calculating mathematically, along with the use of a CAD program, the most efficient way of accelerating incoming and outgoing gases.

Second, our design will eliminate the *camshaft*, *valve springs*, and in some cases *lifters* and *pushrods* from the engine and allow infinite adjustment of *valve* to *crankshaft* timing, unlike the camshaft driven *poppet valve*. This will be done by controlling valve opening by a *restrictor plate* that will only allow flow at determined crank degrees. We also expect to calculate energy losses due to *camshaft* and *valve spring* motion that will not be a factor in an engine with our design. These energy losses that will be eliminated should be transferred directly to an increase in engine output.

Third, our design considerations for sealing should allow for a reliable seal that has a life equal to that of the rest of the engine. We plan to use the concept of compression sealing, found in the *poppet valve* design, in a sense that the pressure inside the *combustion chamber* aids in the sealing of the *valve*. In our design, *combustion chamber* pressure will force the *restrictor plate* into the bottom of the *valve*, thus creating a seal that is stronger as *combustion chamber* pressures increase.

From a design perspective, the most difficult and costly part involved may be the *valve* itself. Our *valve* will have a complicated screw type shape that will be designed in a 3D CAD program. We intend to use this CAD model to obtain a rapid prototype for testing. We will then analyze the prototype from a cost standpoint. Our part will require a mold to be made and will ultimately be cast from stainless steel or mild steel, depending on operating conditions. Cost of this casting is of primary concern, as there are anywhere from 16 to 40 *valves* in an 8 *cylinder* engine. Although only two will be needed for our testing, we must consider the quantity that will be needed for actual production. Other parts, including the *restrictor plate*, the *bearing*, the *retaining ring*, and the *transverse gearing* should be sourced from already manufactured parts, and thus be relatively inexpensive. Our goal for an overall system cost is to be below the cost to equip an engine with all components required to operate a *poppet valve*. The *rotary valve* that we propose requires far fewer individual, moving parts than the traditional *poppet valve design*.

If cost proves to be an issue in producing a *rotary valve* in a screw configuration as we propose, we can simplify our *valve* design in a way that most flow enhancing benefits are lost, but part manufacturability increases drastically. Our *valve* can be configured in such a way that it can be cut from stock material on a lathe and finished on a milling machine. This will leave our proposed *valve-train* unchanged, our cam timing ability unchanged, and also our sealing ability unchanged.

Our valve design will be of primary focus in analysis. We intend to mathematically calculate the most efficient screw configuration and design the *valve* on CAD. Upon obtaining a prototype, we intend to modify an actual *cylinder head* to accept our new *valve*. This will be a relatively simple operation carried out on a milling machine.

After fitting our *valve* to a *cylinder head*, we intend to test airflow through the *valve* at various valve openings and compare this data to that of the same *cylinder head* equipped with its original *poppet valve*. Our *valve* will not be rotating during this stage of testing, thus eliminating all benefits of screw compressing. This will be done by using a professional *flow bench* that our team will have access to.

After completing these initial tests and analyzing the results, we plan to fabricate an engine stand in which our prototype *rotary valve* equipped *cylinder head*, as well as the same *cylinder head* with the standard *poppet valve* are bolted to a *V- style engine*. We plan to actuate the *poppet valves* on one bank of the engine with the standard *camshaft*, and we intend to actuate our *rotary valves* with a transverse gearing system that is powered directly from the crank. Our arrangement will be such that either bank of the engine, and correspondingly either valve system, can be operated independently of the other, or simultaneously. We then intend to rotate the engine electrically with a separate source. This will allow us to take an enormous amount of comparative data including cylinder cranking pressures, which will allow us to compare sealing ability of the two valve systems; air flow in and out of each respective *cylinder*, which will allow us to fully realize the potential benefits of the screw design incorporated in our *valve* and compare it to that of the *poppet valve*; and finally, electric motor lag experienced with each of the valve systems disengaged, which will allow us to calculate energy losses of each respective valve system and compare them.

These three dynamic tests should allow us to adequately test and compare our *rotary valve* with the *poppet valve* in the three areas that we considered to be of importance in our design.

Economic Analysis

For our design, we plan to build a prototype. We have located a company by the name of American Precision Prototyping (APP) that will produce a rapid-prototype made of polypropylene from a CAD drawing. The estimated quote is $143 for our part [2]. We are also considering a rapid metal casting from APP. Another resource available to us is Drexel University's machine shop. However, we plan to make use of Michael Brigidi's fully equipped home garage to save costs. There, we will have access to an engine that we will modify to implement our design and test for parameters.

Utilizing standard production techniques while remaining within acceptable engineering standards and tolerances relating to current production line technology, the design can be manufactured at a substantial savings due to fewer components – which leads to lower costs.

Environmental and Societal Impacts

We believe it's every corporate citizen's responsibility to help protect our planet's environment and to conserve energy so all future generations may enjoy the same beautiful green planet we have. For many years, the environmental and societal requirement for engines has been to become ever more efficient and environmentally safer. Our environmental mission of rotating valve technology is to protect the environment through reduced emissions and energy consumption.

We anticipate that rotary valve technology in engines will offer the following environmental benefits:

- Reduced Emissions: gases such as carbon monoxide (CO) and hydrocarbons (H_XC_Y) will be significantly reduced in rotary valve engines because theoretically, less oil is burned in the *combustion chamber*. Keeping oil from burning inside the *combustion chamber* also lessens oil consumption. Extensive research performed by Coates International has proven that eliminating oil from the *combustion chamber* will allow the engine to run more effectively [1].
- Reduced Fuel Consumption: consumption of gasoline will reduce because of the *rotary valve*'s high volumetric efficiency.
- Reduced Oil Changes and Engine Maintenance: rotary valve technology will keep fuel from the *combustion chamber* to leak out and contaminate the engine oil, therefore leading to cleaner oil, thus, fewer oil changes. General engine maintenance is reduced as well due to fewer parts and the absence of counter pumping motions.

Furthermore, to advance local societal responsibilities, implementation of manufacturing processes, design facilities, and property management will be performed with minimal environmental impact. Rotary valve technology will potentially revolutionize engine manufacturing and design.

Project Planning and Management

Our project planning and management is presented in the form of Gantt charts in Appendix A. Appendix A.1 represents our scheduled team meetings throughout our design project. Appendix A.2 shows our projected assigned tasks and milestones to successfully complete the project.

Summary

This design project as we envision it will require hours of intense research and testing by the design team to study all of the above aspects of the proposed rotary valve design. We intend to create a prototype rotary valve system and determine whether our proposed design will prove to be more efficient. We will do so by comparing our test data acquired to that of a standard poppet valve system. Increased airflow, reduced frictional losses, and proper sealing should ultimately allow the engine to run more effectively. Product efficiency and performance are among the most important characteristics that a customer demands when purchasing a new product.

References

1. *Coates at the Forefront of Technology*, Coates International, Ltd., November 2003.
(http://www.coatesengine.com)

2. *Excellence in Rapid Prototyping Technologies,* American Precision Prototyping, November 2003.
(http://www.approto.com)

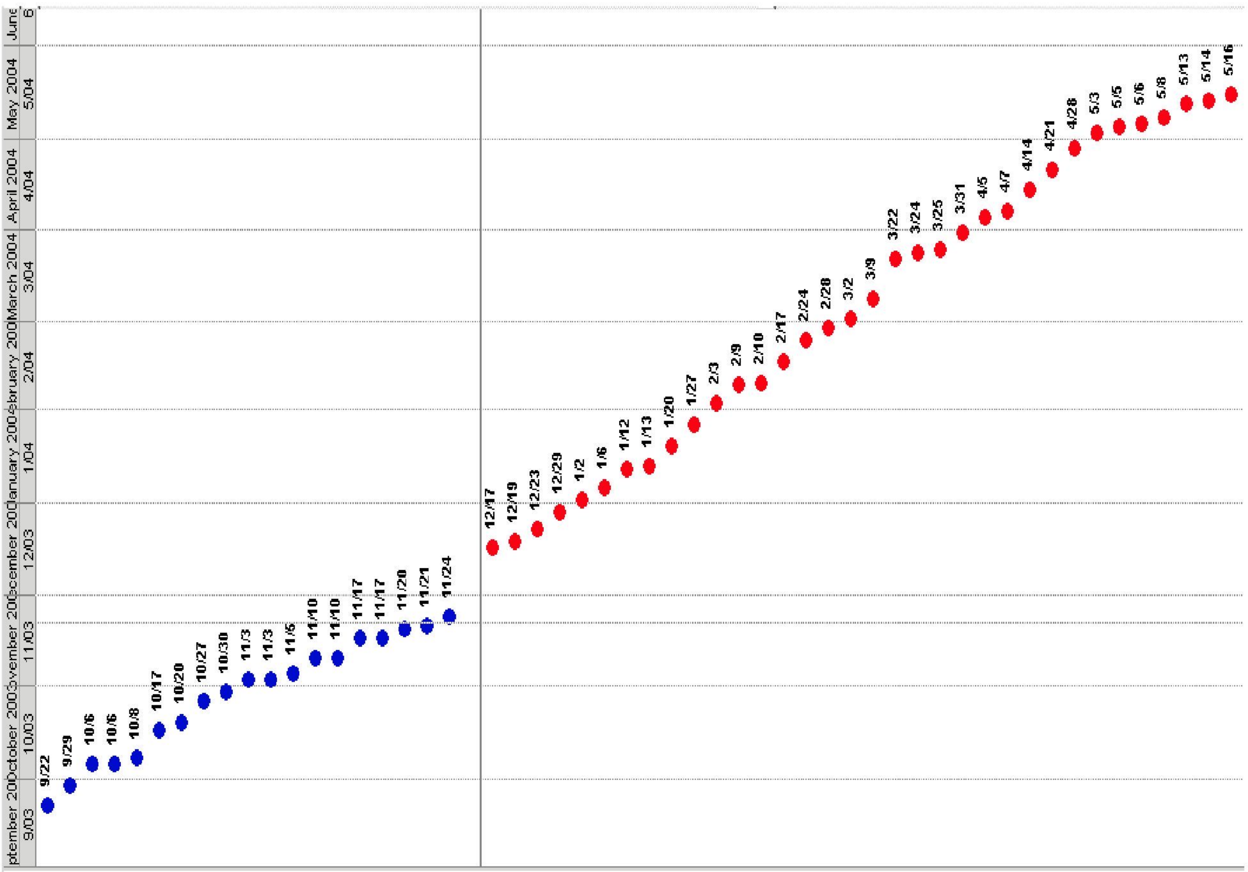
3. Ferguson, C. R., Kirkpatrick, A. T., *Internal Combustion Engines: Applied Thermosciences*, Second Edition, Wiley & Son, November 2000.

4. Stephens, Chris, *Reinventing the Combustion Engine*, March 2003.
(http://www.carcentral.net/content/articles/Reinventing_The_Combustion_Engine.php)

5. *We Build Tomorrow's Technicians,* Abby Senior Mechanics Home Page, October 1999.
(http://abbysenior.com/mechanics/valve.htm)

Appendix A: Project Planning and Management

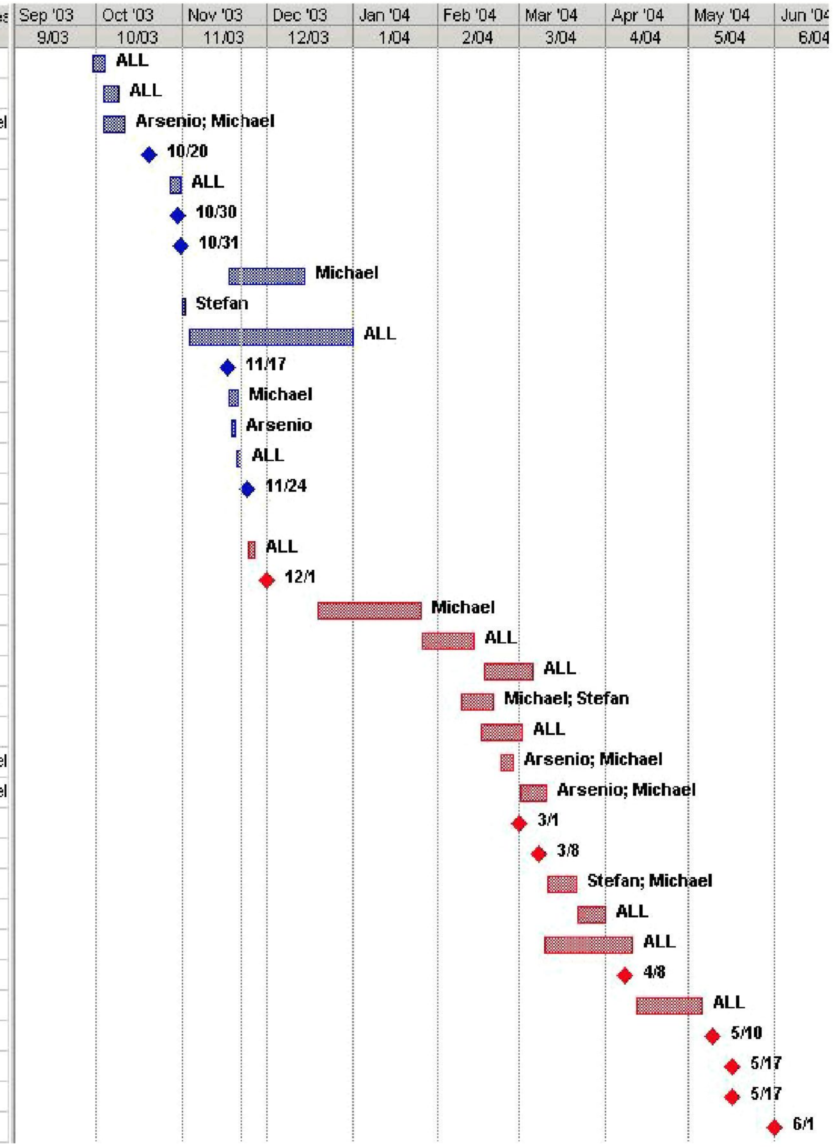
A.1: Scheduled Team Meetings. *Note: meetings to date (actual meetings) are marked with blue dot, while projected meetings are with red dot.*



	Task Name	Duration	Date
1	Weekly Lecture - MEM491	1 hr	Mon 9/22/03
2	Weekly Lecture - MEM491	1 hr	Mon 9/29/03
3	Weekly Lecture - MEM491	1 hr	Mon 10/6/03
4	Forming Team, Introducing Members	0.5 hrs	Mon 10/6/03
5	Choosing Topic, Discussing Details, Assigning Tasks	8 hrs	Wed 10/8/03
6	Discussion of Pre-Proposal - Opinions and Suggestions	0.5 hrs	Fri 10/17/03
7	Weekly Lecture - MEM491	1 hr	Mon 10/20/03
8	Weekly Lecture - MEM491	1 hr	Mon 10/27/03
9	Final Revision of Pre-Proposal	0.5 hrs	Thu 10/30/03
10	Weekly Lecture - MEM491	1 hr	Mon 11/3/03
11	Discussion of Solid Model	1 hr	Mon 11/3/03
12	Quotes for Rapid Prototyping, Suggestions for Prototype	2 hrs	Wed 11/5/03
13	Distribution of Sections (Proposal) Among Teammates	0.5 hrs	Mon 11/10/03
14	Weekly Lecture - MEM491	1 hr	Mon 11/10/03
15	Weekly Lecture - MEM491	1 hr	Mon 11/17/03
16	Proposal Revision, Additional Comments and Suggestions	2 hrs	Mon 11/17/03
17	Meeting with Advisor - Discussion of Preliminary Proposal	0.5 hrs	Thu 11/20/03
18	Final Revision of Proposal	5 hrs	NA
19	Weekly Lecture - MEM491	1 hr	Mon 11/24/03
20			
21	Weekly Team Meeting	1 hr	Wed 12/17/03
22	Weekly Team Meeting	1 hr	Fri 12/19/03
23	Weekly Team Meeting	1 hr	Tue 12/23/03
24	Weekly Team Meeting	1 hr	Mon 12/29/03
25	Weekly Team Meeting	1 hr	Fri 1/2/04
26	Weekly Team Meeting	1 hr	Tue 1/6/04
27	Social Meeting with Senior Design Coordinator	1 hr	Mon 1/12/04
28	Weekly Team Meeting	1 hr	Tue 1/6/04
29	Weekly Team Meeting	1 hr	Tue 1/20/04
30	Weekly Team Meeting	1 hr	Tue 1/27/04
31	Weekly Team Meeting	1 hr	Tue 2/3/04
32	Social Meeting with Senior Design Coordinator	1 hr	Mon 2/9/04
33	Weekly Team Meeting	1 hr	Tue 2/10/04
34	Weekly Team Meeting	1 hr	Tue 2/17/04
35	Weekly Team Meeting	1 hr	Tue 2/24/04
36	Preparation for Progress Report Presentation	2 hrs	Sat 2/28/04
37	Weekly Team Meeting	1 hr	Tue 3/2/04
38	Weekly Team Meeting	1 hr	Tue 3/9/04
39	Weekly Team Meeting	1 hr	Mon 3/22/04
40	Weekly Team Meeting	1 hr	Wed 3/24/04
41	Weekly Team Meeting	1 hr	Thu 3/25/04
42	Weekly Team Meeting	1 hr	Wed 3/31/04
43	Social Meeting with Senior Design Coordinator	1 hr	Mon 4/5/04
44	Weekly Team Meeting	1 hr	Wed 4/7/04
45	Weekly Team Meeting	1 hr	Wed 4/14/04
46	Weekly Team Meeting	1 hr	Wed 4/21/04
47	Weekly Team Meeting	1 hr	Wed 4/28/04
48	Social Meeting with Senior Design Coordinator	1 hr	Mon 5/3/04
49	Weekly Team Meeting	1 hr	Wed 5/5/04
50	Revision - Final Report	1 hr	Thu 5/6/04
51	Revision - Final Report	1 hr	Sat 5/8/04
52	Preparation for Senior Design Presentation	2 hrs	Thu 5/13/04
53	Preparation for Senior Design Presentation	2 hrs	Fri 5/14/04
54	Preparation for Senior Design Presentation	2 hrs	Sun 5/16/04

A.2: Projected Tasks and Milestones. *Note: Activities to date are marked in blue. Future milestones and assignments are in red*

	Task Name	Start	Finish	Resource Names
1	Forming Team	Mon 9/29/03	Fri 10/3/03	ALL
2	Brainstorming for Topic	Fri 10/3/03	Wed 10/8/03	ALL
3	Looking for Advisor	Fri 10/3/03	Fri 10/10/03	Arsenio; Michael
4	Pre-Proposal Submittal	Mon 10/20/03	Mon 10/20/03	ALL
5	Revision of Pre-Proposal	Mon 10/27/03	Thu 10/30/03	ALL
6	Meeting with Advisor - Pre-Proposal	Thu 10/30/03	Thu 10/30/03	ALL
7	Pre-Proposal Submittal	Fri 10/31/03	Fri 10/31/03	Michael
8	Work on Solid Model	Mon 11/17/03	Sun 12/14/03	Michael
9	Obtaining Quote Info for Rapid Prototyping	Fri 10/31/03	Sat 11/1/03	Stefan
10	Research for Similar Products	Mon 11/3/03	Wed 12/31/03	ALL
11	Complete Proposal and Put Sections Together	Mon 11/17/03	Mon 11/17/03	ALL
12	Submit to Advisor for Review	Mon 11/17/03	Thu 11/20/03	Michael
13	Submit to Tutor for Proofreading	Tue 11/18/03	Wed 11/19/03	Arsenio
14	Make Corrections to Proposal	Thu 11/20/03	Fri 11/21/03	ALL
15	Submit Proposal	Mon 11/24/03	Mon 11/24/03	ALL
16				
17	Work on Presentation Slides	Mon 11/24/03	Wed 11/26/03	ALL
18	Presentation of Proposal	Mon 12/1/03	Mon 12/1/03	ALL
19	Revision of Solid Model	Fri 12/19/03	Sun 1/25/04	Michael
20	Send Model for Rapid Prototyping	Mon 1/26/04	Fri 2/13/04	ALL
21	Send Model for Casting	Tue 2/17/04	Fri 3/5/04	ALL
22	Modify Engine Head to Accept Rotary Valve	Mon 2/9/04	Fri 2/20/04	Michael; Stefan
23	Preparation of Progress Report/Presentation	Mon 2/16/04	Mon 3/1/04	ALL
24	Build a Test Stand	Mon 2/23/04	Fri 2/27/04	Arsenio; Michael
25	Static Valve Flow Testing	Mon 3/1/04	Wed 3/10/04	Arsenio; Michael
26	Progress Report Presentation	Mon 3/1/04	Mon 3/1/04	ALL
27	Submit Progress Report	Mon 3/8/04	Mon 3/8/04	Michael
28	Dynamic Valve Flow Testing	Thu 3/11/04	Sun 3/21/04	Stefan; Michael
29	Compression Testing	Mon 3/22/04	Wed 3/31/04	ALL
30	Analyzing Test Data	Wed 3/10/04	Sat 4/10/04	ALL
31	Submit Project Abstract	Thu 4/8/04	Thu 4/8/04	Stefan
32	Preparation of Final Report/Presentation	Mon 4/12/04	Wed 5/5/04	ALL
33	Submit Final Project Report	Mon 5/10/04	Mon 5/10/04	Stefan
34	Senior Design Final Presentation	Mon 5/17/04	Mon 5/17/04	ALL
35	Submit Final Project Presentation	Mon 5/17/04	Mon 5/17/04	ALL
36	Senior Design Project Completion	Tue 6/1/04	Tue 6/1/04	ALL



Appendix B: GLOSSARY of the More Important Terms Used in This Paper

bearing – used in an engine in any place of rotational or translational metal to metal contact. Engines typically use journal bearings and rely heavily on oil pressure.

camshaft – a metal shaft consisting of off-center lobes, located above the engine block, which is mechanically connected to the crankshaft. Its primary purpose is to open and close the valves at certain intervals.

combustion chamber – the empty space between the piston and the engine head inside the engine block when the piston is at top dead center, or in the fully upward position. Combustion process (ignition of air/fuel mixture) takes place in the combustion chamber.

crankshaft – a shaft which is mechanically connected to the pistons. When the pistons oscillate, their movement is transformed into rotary motion via the crankshaft and then transferred to the gearbox. It is located underneath the pistons.

cylinder – as the name implies, this void inside the engine block, has cylindrical shape. This is the space where the pistons move up and down.

cylinder head – installed above the block. It plays important role in the engine configuration. It is responsible for housing flow into and out of the combustion chamber, as well as combustion itself. Most of the valve-train components are in the cylinder head.

exhaust valve – allows the exhaust gases to enter the exhaust manifold, away from the combustion chamber.

flow bench – test set-up where cylinder head is connected to an external source of air flow and the components are moved so that flow through the combustion chamber can be observed and measured.

intake valve – introduces the fresh air/fuel mixture to the combustion chamber.

internal combustion engine – type of engine where burning of the combustible material (gasoline, natural gas, diesel fuel) takes place inside the engine, as opposed to external furnace (steam engine).

lifter – metal cylinder specifically designed to follow the camshaft and open the valves. A lifter can either be a solid piece of metal or it can have moving parts and keep pressure on the drive-train hydraulically using engine oil pressure.

poppet valve – the most common valve design used in the internal combustion engines. Its shape reminds of the letter T viewed upside down.

pushrod – similar to a lifter in it translates motion from the camshaft to the valves. Pushrods are found in some overhead valve engines and are long and thin solid tubes. They usually double as an oil transporter.

restrictor plate – paired with the rotary valve, the restrictor plate will serve to block the flow when the valve is not in proper position, thus providing sufficient sealing.

retaining ring – provides that the restrictor plate will stay in place in the engine head.

rocker arm – lever, used to transfer the motion of the pushrod or lifter to the valve.

rotary valve – the main objective of this design. The valve will rotate instead of oscillate (poppet valves) and will force flow in and out of the combustion chamber.

transverse gearing – this will change the direction of rotation exactly 90 degrees. This is necessary in order to rotate a rotary valve using the crankshaft.

valve – device that regulates the flow of a fluid in a given direction.

valve seat – usually a machined section of the engine head, where poppet valve's bottom returns after being closed. It provides proper sealing of the combustion chamber.

valve spring – ensures that the poppet valve will return to its original closed position after the pressure from the camshaft is removed.

valve timing – specific adjustment of the valve-train allowing only certain valves to open at exactly specified time periods.

valve-train – the combination of parts (camshaft, valves, springs, etc.) that provide proper intake and exhaust inside the combustion chamber.

V-style engine – internal combustion engine, where the engine block is divided into two cylinder banks, thus forming a V shape.

Appendix C: Team Member Resumes

C.1: Arsenio Garza

C.2: Stefan Kratounov

C.3: Michael Brigidi